in the element of thickness dr is independent of r, then we can write $dN=kdr$ where k is a constant. From relation (1), we obtain

$$dS=-(\log 2/a)[S-(p-s)]dr$$

or

$$dr=-adS/\{\log 2[S-(p-s)]\}.$$

Then the form of the distribution curve will be given by

$$dN=-\frac{ak/\log 2}{S-(p-s)};\quad dS=-\frac{A}{S-b}dS.$$

This depends on only two parameters, and we may fit it to the observed distribution curves. The data of Steinke and Schindler are unsuitable for consideration in the present connection since they give a distribution curve for the difference in size of Stösse occurring simultaneously in two chambers placed side by side. However, we can compare Messerschmidt's results and those obtained at the Bartol Foundation with this empirical formula. The accompanying curves show how well this elementary theory fits the observations. For Messerschmidt's data, we obtain $A=75$, $b=6.53\times10^6$ ions, and for the Bartol data $A=26$, $b=5.02\times10^6$ ions. b represents the difference in size of a primary and a secondary group, while $A=ak/\log 2$, where k is the total number of primary groups per centimeter. Since the observations do not extend to sufficiently small sizes, we can only set a lower limit to it. For the Bartol data, $D=2.5$ cm iron, $k>59$ and hence $a<0.3$ cm. For Messerschmidt's data, $D=10$ cm lead, $k>81$ and $a<0.6$ cm.

We see that the observed curves, in their middle range at least, are well represented by such a picture of the Stoss-forming process as is given here. The deviations at either end are certainly to be ascribed to the overly simplified picture used. An elaboration of the theory would involve a closer specification of the probabilities of formation of the secondary groups, rather than the assumption that they are all equal. Although this would improve the agreement, it would only tend to complicate the calculations and would add nothing to the picture of the mechanism. However, the agreement is certainly good enough to regard the model used as a fair approximation to what actually happens. It is to be noticed that the essential idea in the process is that all groups, whether primary or secondary, are capable of producing other groups. The application of the picture of a primary group producing secondary groups all along its path (S in this case would vary linearly with r) is not capable of giving a distribution curve of the type observed.

The real importance of this picture of the formation of Stösse lies in the predictions that can be made from it. First, there should be a lower limit to the sizes of Stösse, and this limit is the size of the primary group of rays. If an upper limit of size exists, it probably depends upon the energy of the primary cosmic ray. Second, the distribution curves of Stoss sizes will depend upon the thickness of the material from which the Stösse come: thicker materials should give larger Stösse. There should also be observed "transition" effects if there is a primary or secondary Stoss size characteristic of the material. The lower limit of the size should, however, be dependent only upon the last material through which the Stoss particles pass.

In conclusion, the author wishes to express his thanks to Dr. W. F. G. Swann for his helpful encouragement and discussion of the ideas involved here.

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Bartol Research Foundation
of The Franklin Institute,
November 26, 1933.

[4] The "2" in this expression results from the assumption that the number of groups doubles every "a" centimeters. As Dr. Swann has pointed out to the author, if the number of groups is derived by an integration process, the "2" becomes an "e."

Gamma-Rays from Lithium Bombarded with Protons

In a previous letter to the *Physical Review*[1] we reported the production of neutrons by the bombardment of lithium chloride with hydrogen ions. The measurements were made with an ionization chamber lined with paraffin and enclosed in a lead cylinder of 5 cm wall thickness. That the ionization was, in part at least, due to neutrons was concluded from the observation that less ionization was observed when the paraffin was removed from the chamber. We observed, however, that the difference in ionization with and without paraffin was in this case less than in the measurements of neutrons produced by other disintegrations previously investigated by us. This suggested that in the case of lithium a considerable part of the ionization might be due to γ-rays.

It is well established that lithium when bombarded with protons yields a group of long range α-particles and one or more groups of shorter range. Oliphant, Kinsey and Rutherfore[2] have recently made very careful measurements of the ranges and numbers of these particles and have found ranges of 0.65, 1.15 and 8.3 cm, the relative numbers of which are 0.5, 1 and 1, respectively. The 8.3 cm particles are satisfactorily accounted for by the reaction $Li^7+H^1\rightarrow 2He^4$, but this does not explain the two short range groups observed, unless the excess energy (about 12×10^6 e.v.) goes into a γ-ray. A search for such γ-rays has been made by Traubenberg, Eckartt and Gebauer,[3] but the evidence is not very conclusive. It is clear, therefore, that if all of these particles result from the disintegration of Li^7 with protons, the process must be more complicated than indicated by the above equation.

[1] Crane and Lauritsen, Phys. Rev. **44**, 783 (1933).

[2] Oliphant, Kinsey and Rutherford, Proc. Roy. Soc. **A141**, 722 (1933).

[3] Traubenberg, Eckartt and Gebauer, Zeits. f. Physik **80**, 557 (1933).

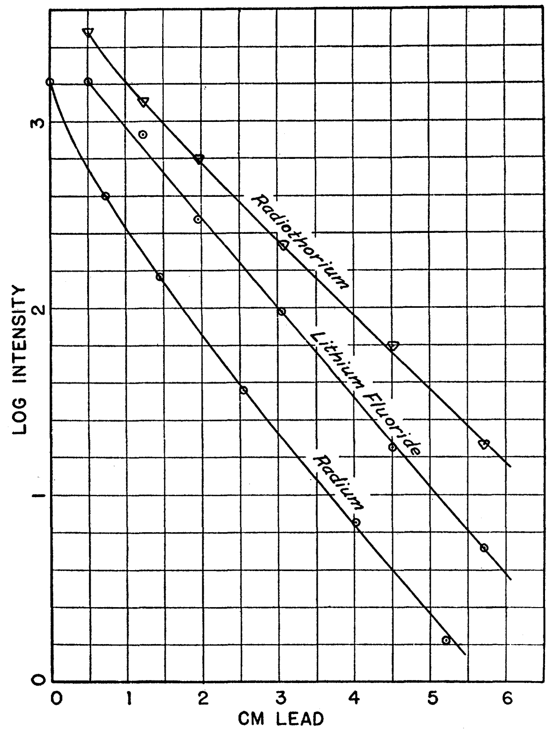

FIG. 1. Absorption of rays in lead.

To investigate the problem more closely, we have made provision for varying the amount of lead between the target and the ionization chamber. Measurements with much reduced lead filtration produced a large increase in the ionization which enabled us to make absorption measurements. The presence of strong γ-radiation was indicated by the observation that the absorption, per electron, was nearly the same for lead as for paraffin. The experimental arrangement was not suitable for an absolute determination of absorption coefficients as it was necessary to use a rather large solid angle. For this reason the absorption was compared directly with the absorption of γ-rays from radium and thorium sources placed in the exact position of the target.

The results of such a series of measurements at 600 kv with a lithium fluoride target and lead absorbers are shown in Fig. 1, from which we conclude that the γ-rays from lithium fluoride have about the same quantum energy as γ-rays from radium filtered through about 2 cm of lead. The plot is a straight line, within the accuracy of our measurements, indicating that the radiation is monochromatic, or at least nearly so. There is no evidence of a component of much harder radiation and, if such a component is present, it must be of very much smaller intensity. It is tempting to associate this γ-radiation with the short range α-particles, as the quantum energy corresponds approximately to the energy difference between two 1.15 cm particles and two 0.65 cm particles, namely, about 1.5×10^6 e.v.

It may be of interest to note that the intensity of γ-radiation at 600 kv and 20 microamperes ion current is about equal to that from 0.1 milligram of radium. The number of quanta is therefore not very different from the number of α-particles in the 1.15 cm group, thus giving support to the above suggestion.

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December 1, 1933.

The Nature of the "Forbidden" Lines in the Pb I Spectrum

In a recent letter to the *Physical Review*,[1] one of us has reported the appearance of some Pb I lines which are forbidden for the normal dipole radiation. These lines were obtained in the spectrum of high frequency electric discharges in mixtures of lead vapor with inert gases.

The strongest of these lines λ4618.0A, corresponding to the transition from $6p^2\,{}^1S_0$ to $6p^2\,{}^3P_1$ energy level, cannot be explained by quadrupole radiation as violating the $0\rightarrow 1$ interdiction for the change of the resultant angular momentum quantum number J. The appearance of this line was therefore attributed to the electrically perturbed dipole radiation although the absence of sufficiently strong external or intermolecular electric fields hardly supports this view. Hence the remaining "forbidden" lines λ4659.4 ($6p^2\,{}^3P_0-6p^2\,{}^1D_2$), λ5312.7 ($6p^2\,{}^3P_2-6p^2\,{}^1S_0$) and λ7330 ($6p^2\,{}^3P_1-6p^2\,{}^1D_2$) which are allowed for the quadrupole radiation could also be interpreted as the electrically perturbed dipole radiation.

The emission of the line λ4618.0 can be explained however by the *magnetic dipole radiation* thus avoiding the hypothesis of strong electric fields under the described experimental conditions. A detailed examination, which will be published shortly, has shown that there exists a finite probability of the transitions from the energy state ${}^1S_0$ to that ${}^3P_1$ for the magnetic dipole radiation. Brinkman's[2] selection rules for the change of the quantum numbers L and S in the magnetic dipole radiation ($\Delta L=0$ and $\Delta S=0$) cannot be applied here since they are strictly valid only for extreme Russell-Saunders coupling for which electric dipole and quadrupole intercombination lines are also forbidden. A deviation from Russell-Saunders coupling in the case of the energy states of the neutral lead atom belonging to the electron configuration $6s^2\,6p^2$ is indicated by the wide relative separation of the ${}^3P$ levels.

[1] H. Niewodniczański, Phys. Rev. **44**, 854 (1933).

[2] H. C. Brinkman, Dissertation, Utrecht (1932), also quoted by A. Rubinowicz and J. Blaton, Ergebnisse der exakten Naturwiss. **11**, 190 (1932).